

METHODS, AMOUNTS, AND TIMING OF SPRINKLER IRRIGATION FOR WINTER WHEAT

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ABSTRACT. *The yield response of winter wheat to LEPA double-ended-sock, LEPA bubble and overhead spray sprinkler methods was measured in the Southern High Plains with four irrigation amount and two irrigation timing treatments. Irrigation amount treatments ranged from zero to 100% of soil water replenishment in 33% increments. Irrigation timing treatments were shortening the 100% irrigation season by delaying irrigation until booting or by terminating irrigation during early grain filling. TAM 202 variety wheat was raised on Pullman clay loam soil, and irrigations were applied with a lateral move irrigation system during the 1993-1994 and 1994-95 cropping seasons. Grain yields did not vary significantly among the spray and LEPA sprinkler methods although in 1995 yields with the spray method were generally larger. In 1994, grain yields increased a statistically significant 1 Mg/ha for each 33% increase in irrigation, but significant yield increases occurred only for the first two irrigation increments in 1995. Deficit irrigation with the 33% and 66% irrigation amounts, generally increased the grain yield per unit of irrigation water more than deficit irrigation with the two irrigation timing treatments.* **Keywords.** *Irrigation, Sprinkler, Winter wheat, Spray, LEPA, Deficit.*

Winter wheat, a major irrigated crop on fine-textured soils in the Southern High Plains, was initially surface irrigated but is now extensively irrigated with center pivot irrigation systems (Musick et al., 1988). In a pioneering study, Jensen and Sletten (1965) estimated evapotranspiration (ET) for winter wheat and provided guidelines for irrigation and fertility management. With "Concho" variety wheat, their three-year average high yields were about 3.1 Mg/ha. The corresponding water use efficiency (WUE) defined as grain yield divided by evapotranspiration (ET) was 0.44 kg/m³. Since then, wheat yields and water use efficiencies have increased substantially with the increase primarily due to the release of high-yielding, semi-dwarf cultivars. With "Tascosa" grown in the late 1960s Schneider et al. (1969) reported a WUE of 0.54 kg/m³, and Musick et al. (1994) reported a WUE of 0.94 kg/m³ with semi-dwarf cultivars grown during the 1979-1982 interval. Irrigation management guidelines for winter wheat in the Southern High Plains of the USA have been summarized by Musick and Porter (1990).

Evapotranspiration measurements have been made by several researchers in the Southern High Plains. Based on their three-year study, Jensen and Sletten (1965) estimated

seasonal ET as 711 mm. In an analysis of a 178 crop-year data base of both dryland and irrigated wheat, Musick et al. (1994) determined a 206-mm ET threshold for the first wheat yield increment, and an average seasonal ET of 733 mm for adequately irrigated wheat. Howell et al. (1995) observed a seasonal ET range of 791 to 957 mm during three years of measurements with weighing lysimeters.

Winter wheat can be efficiently deficit-irrigated over a large range of irrigation amounts, seasonal ET, and grain yields (Dusek and Musick, 1992; English and Nakamura, 1989; Musick et al., 1994; Schneider et al., 1969). Wheat has the potential for efficient use of small irrigation amounts applied throughout the growing season (English and Nakamura, 1989). Data presented by Musick et al. (1994) show, that for irrigated wheat, similar WUE values can occur over a wide range of seasonal ET. Wheat also has the potential to efficiently utilize large irrigations at critical growth stages (Dusek and Musick, 1992; Schneider et al., 1969). Wheat is most sensitive to water deficits during the booting through early grain filling growth stages. During spring growth through jointing, ET rates are lower, water deficits are not severe, and irrigation prior to boot stage often has limited effect on grain yields. After early grain filling, plants can translocate nutrients from stems and leaves to the seeds. As a result, high water use efficiencies are often obtained by delaying early spring irrigation or by early termination of irrigation (Dusek and Musick, 1992; Schneider et al., 1969).

Sprinkler irrigation in the Southern High Plains has undergone nearly a complete transition from impact sprinklers to spray heads placed above or within the growing crop (Musick and Walker, 1987). For row crops there has been an additional transition from spray systems to Low Energy Precision Application (LEPA) systems (Fipps and New, 1990). LEPA irrigation offers the potential to substantially increase application efficiency in comparison with spray irrigation (Lyle and Bordovsky,

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1981, 1983; Schneider and Howell, 1990); however, LEPA requires higher levels of management. During recent years, some growers have used LEPA systems to irrigate winter wheat that is flat-planted in closely spaced rows and has no surface reservoir capacity to store water applied at high rates. In addition, all wheat plants are not equally spaced from a LEPA emitter as they are with row crops.

In this study we compared LEPA and spray irrigation for winter wheat with full irrigation and three deficit irrigation amounts based on percentages of full irrigation. Two additional deficit irrigation treatments were shortening the 100% irrigation season by delaying irrigation until booting or by terminating irrigation during early grain filling. The objective was to determine if LEPA irrigation increases water use efficiency by eliminating evaporation and drift losses in the air and reducing evaporation losses from the crop canopy and soil.

PROCEDURE

The research was conducted at the USDA Conservation and Production Research Laboratory at Bushland, Texas (35°11' N lat., 102°06' W long., 1170 m msl elevation) during the 1993-1994 and 1994-1995 winter wheat seasons. The soil at the site is Pullman clay loam, a fine, mixed, thermic torrertic Paleustoll, with a dense B2t subsoil from about 150 to 400 mm and calcic horizon depths of 1000 to 1500 mm. For the upper 1.0 m soil profile, Unger and Pringle (1981) measured 139 mm of available water capacity between the 0.033 and 1.5-MPa matric potentials, and 144 mm of plant available water was measured in field plots (J. T. Musick, Personal Communication). The research field had a uniform slope of 0.0025 m/m in the direction of travel of the lateral move irrigation system and a 0.0022 m/m cross slope.

EXPERIMENTAL DESIGN

One spray and two LEPA sprinkler application methods (table 1) were evaluated with four irrigation amount treatments and two irrigation timing treatments. LEPA irrigation methods were double-ended, Fangmeier, LEPA drag socks (Fangmeier et al., 1990), designated as M_1 , and LEPA bubble emitters (Fipps and New, 1990), designated as M_2 . The Fangmeier socks were dragged along the ground, and the LEPA bubble emitters discharged water about 0.3 m above ground level. Above canopy spray heads, designated as M_3 , were positioned about 1.5 m above the ground. Field plots were arranged in a randomized block design with irrigation treatments being the blocks and sprinkler methods being randomized within the blocks. Each of the 18 treatments was replicated three

times — once under each span of the irrigation system. Plots were 12 m wide (parallel to the irrigation system) by 20 m long (perpendicular to the irrigation system).

A fully irrigated control treatment and five deficit-irrigated treatments were evaluated with the three sprinkler methods. Irrigations were scheduled according to the average soil water content in the treatment fully-irrigated with LEPA double-ended socks (I_{100}/M_1). Irrigations were applied to maintain the soil water content in the 1.0-m deep profile (zone of major water extraction) of the I_{100}/M_1 control treatment above 70% of plant available water, or approximately 296 mm of total soil water for the Pullman clay loam soil. Other irrigation amount treatments designated as I_0 , I_{33} , and I_{67} received 0, 33 or 67% of applications to the fully irrigated treatments on the same day. The irrigation timing treatments received the same-sized irrigations as I_{100} , but spring irrigation was delayed until early boot stage on treatment I_D and terminated during early grain filling on treatment I_E .

Gravimetric and neutron soil water measurements provided data for growing season soil water depletion, calculation of seasonal ET and irrigation scheduling. All plots were gravimetrically sampled in 0.3-m increments to a 1.8-m depth after planting and after harvest. Soil water contents in the I_{100} irrigation plots were measured in 0.2-m depth increments to the 2.4-m depth with a locally field calibrated CPN Model 503DR neutron moisture meter. From the start of spring growth until crop maturity, weekly neutron soil water measurements were made for irrigation scheduling except during intervals when rainfall made irrigation unnecessary.

IRRIGATION EQUIPMENT

Irrigations were applied with a hose-fed Valmont Model 6000 lateral-move irrigation system equipped with a CAMS computerized controller. The system had three, 39-m long spans with twenty-four, 1.52-m spaced drops under each span. Pressurized water, on demand from a surface reservoir, was supplied to the irrigation system through an underground pipeline and a 114-mm diameter surface hose. Information about the three sprinkler devices is listed in table 1. Senninger 360° spray nozzles placed above the LEPA socks metered the flow to the drag socks at the same rate as the other devices. All application devices were spaced 1.52 m apart and discharged 19.0 L/min — equivalent to the discharge rate at the end of a 400-m center pivot with a supply rate of 2500 L/min. Pressure to the sprinkler irrigation system was 207 kPa. The LEPA devices were equipped with 41-kPa pressure regulators for the 1994 spring irrigations, and all application devices were equipped with pressure regulators for the 1995 spring irrigations. Irrigation amount was varied by changing the speed of the lateral move irrigation system.

CULTURAL PRACTICES

Cultural practices were similar to those generally used for sprinkler-irrigated wheat in the Southern High Plains. Table 2 lists fertilizer rates, plant population and dates of cultural operations and irrigations. In preparation for the 1994 crop, the field was cropped to dryland grain sorghum in 1992 and fallowed with sweep tillage until wheat planting in the fall of 1993. TAM 202 variety wheat was planted on October 6 with a 6.1-m wide Tye grain drill

Table 1. Irrigation application device information

Device	Manufacturer	Model	Nozzle Diameter (mm)
LEPA sock	A.E. Quest & Sons (Senninger)	(360°)*	(6.8)
LEPA bubble	Senninger	Quad IV*	6.8
Overhead spray	Nelson	Spray I	4.6 (6.0)†

* Equipped with 41 kPa pressure regulators.

† Equipped with 69 kPa pressure regulators for 1994-1995.

Table 2. Agronomic and seasonal irrigation data for the two winter wheat crops

Variable	1993-1994	1994-1995
Fertilizer and application date	100 kg(NH ₃ -N)/ha (21 Sept. 1993) 112 kg(P)/ha (August 1992)	135 kg(NH ₃ -N)/ha (22 Sept. 1994) 112 kg(P)/ha (August 1992)
Wheat variety	TAM 202	TAM 202
Planting date	6 Oct. 1993	14 Oct. 1994
Emergence irrigation date	12 Oct. 1993	None
Fall irrigation date	None	31 Oct. 1994
First seasonal irrigation date	23 March 1994	21 March 1995
Last seasonal irrigation date	9 June 1994	23 May 1995
Harvest date	29 June 1994	30 June 1995
Plant population (plants/m ²)	265	277

equipped with 0.25-m spaced double-disk openers. A separate plot area for the 1995 crop was cropped to irrigated grain sorghum during 1992 and fallowed with sweep tillage for two years until planting in the fall of 1994. The second wheat crop was planted on 14 October 1994 with the same grain drill used the previous year. The wheat rows were oriented perpendicular to the direction of travel of the sprinkler system.

Fall and winter irrigations were applied with spray heads only to wet the entire soil surface and provide the opportunity for nodal root growth. All spring irrigations were applied with the three different sprinkler methods. Irrigation blocks were separated by dikes to prevent runoff from wetter plots onto drier ones, and sprinkler method plots were separated by small ditches to prevent runoff from LEPA plots onto spray plots. Some runoff was held by the dikes on the I₁₀₀ irrigation plots, but the quantity of water held by the dikes was small in comparison to total water application.

Grain yield samples were collected on 29 June 1994 and 30 June 1995 with a Hege plot combine equipped with a 1.52-m header. After maturity, plant samples were collected from a 1-m² area in each plot, oven dried at 70°C and weighed to determine total dry matter. The dry matter samples were threshed, and grain weight was measured for determining harvest index. Seed weight was measured with a 1,000-grain subsample. Grain yields were adjusted to 13% water content on a wet weight basis.

RESULTS

IRRIGATION AND RAINFALL

The amount and timing of rainfall and spring irrigations are listed in table 3. Long-term 1 September to 31 May average rainfall at Bushland is 214 mm, and comparable rainfalls for the two respective years of this study were 165 and 217 mm. Although rainfall during the 1995 growing season was average, nearly half of it occurred in May. As a result, winter and early spring rainfall for both crops was below average. A 25-mm emergence irrigation was applied on 12 October 1993 for the first crop. Then, in 1994, the

Table 3. Weekly spring rainfall and irrigation applied to the fully irrigated treatments

Week	Irrigation (mm)	Rainfall (mm)	Weekly Totals (mm)
1994			
20-26 March	25	0	25
27 March-2 April	25	0	25
3-9 April	25	0	25
10-16 April	25	9	34
17-23 April	25	9	34
24-30 April	0	17	17
1-7 May	25	7	32
8-14 May	50	6	56
15-21 May	50	0	50
22-28 May	0	35	35
29 May-4 June	50	9	59
5-11 June	50	8	58
Totals	350	100	450
1995			
19-25 March	50	0	50
26 March- April	25	12	37
2-8 April	25	4	29
9-15 April	50	0	50
16-22 April	50	4	54
23-29 April	25	2	27
30 April-6 May	50	18	68
7-13 May	25	32	57
14-20 May	50	4	54
21-27 May	25	35	60
27 May-3 June	0	71	71
Totals	375	182	557

I₁₀₀ treatments generally received one 25-mm irrigation per week from early March to early May (anthesis) and two 25-mm irrigations per week until early June (late grain filling). Two exceptions were the week of 24-30 April when 17 mm of rainfall occurred and the week of 22-28 May when 35 mm of rainfall occurred. In 1994, spring irrigation totaled 350, 234, and 117 mm for the irrigation amount treatments and 250 mm for both irrigation timing treatments. Because of drier soil conditions for the 1995 crop, all treatments received a 19-mm fall irrigation 31 October and 25-mm winter irrigations on 2 December and 2 February. Early spring soil water

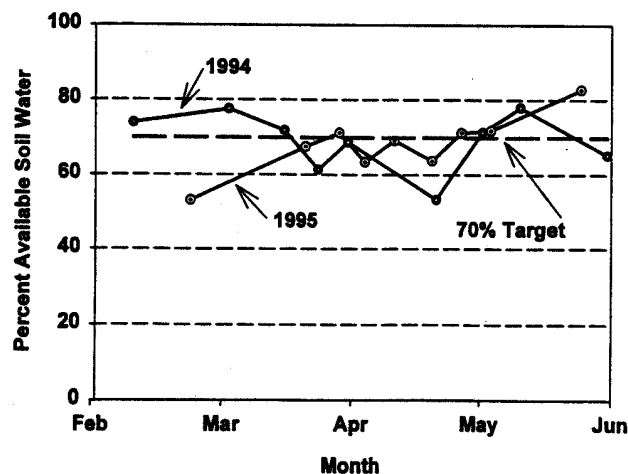


Figure 1—Percent available soil water in the 1.0 deep profile of the treatment 100% irrigated with LEPA drag socks (I₁₀₀/M₁).

contents were lower than in 1994 (fig. 1) and two 25-mm irrigations were applied during the week of 19-25 March. Either 25 or 50 mm of irrigation was then applied each week until rainfall starting on 26 May made additional irrigation unnecessary. The 1995 spring irrigations totaled 375, 250, and 125 mm for the irrigation amount treatments, 275 mm for delayed spring irrigation and 350 mm for early termination of spring irrigation.

SOIL WATER

At planting, the average plant available soil water in the 1.8-m profile was about 170 and 145 mm (70 and 60% of plant available water) for the two respective years. Plant available soil water in the 1.0 m profile is illustrated in figure 1 for the control irrigation treatment (I_{100}/M_1). Soil water during both springs was near the 70% plant available target except for 4 May 1994 and 8 March 1995 when it reached the 55% available level. Depletion to 50% available soil water on Pullman clay loam will not normally result in plant stress with the normal ET rates occurring during these two intervals. Spring soil water contents in the 1.0 m profile of I_{100}/M_1 were relatively constant in 1994 but increased 46 mm in 1995 because of the large amount of late season rainfall.

Soil water depletions for the 1.8-m deep soil profile are listed in tables 4 and 5 for all treatments. Wheat grown on Pullman clay loam has the ability to fully utilize available soil water down to the calcic horizon at the 1.0 to 1.5 m depth. It has reduced extraction ability below this depth because of reduced rooting density. For 1994, the full irrigation treatment (I_{100}) had a mean depletion of 64 mm, the deficit irrigated treatments (I_{67} and I_{33}) had mean depletions of 100 and 87 mm, respectively, and the non-irrigated treatment had a mean depletion of 152 mm. The

Table 4. Grain yields, soil water depletion, ET, water use efficiency, harvest index and seed weight for the 1994 wheat crop

Irrigation Treatment	Sprinkler Method	Soil Water		ET* (mm)	WUE (kg/m ³)	IWUE (kg/m ³)	Harvest Index	Seed Weight (mg)
		Yield (Mg/ha)	Depl. (mm)					
0%	Average	1.67	152	334	0.500	—	0.328	24.7
33%	LEPA sock	2.90	98	396	0.733	1.06	0.313	25.7
	LEPA bubble	2.44	71	369	0.660	0.661	0.334	26.6
	Overhead spray	2.46	93	391	0.629	0.679	0.355	25.6
67%	LEPA sock	3.82	97	513	0.745	0.917	0.345	27.0
	LEPA bubble	3.35	85	501	0.669	0.719	0.339	26.4
	Overhead spray	3.71	117	533	0.696	0.871	0.334	26.9
100%	LEPA sock	4.39	85	617	0.712	0.778	0.336	26.7
	LEPA bubble	4.73	61	593	0.799	0.876	0.359	26.3
	Overhead spray	4.37	46	578	0.757	0.772	0.386	26.7
100% Delayed	LEPA sock	2.97	82	514	0.579	0.521	0.343	22.1
	LEPA bubble	3.22	77	509	0.632	0.620	0.328	23.0
	Overhead spray	3.13	96	528	0.593	0.584	0.394	22.9
100% Early termination	LEPA sock	3.81	129	561	0.679	0.856	0.320	23.3
	LEPA bubble	4.10	96	528	0.777	0.972	0.323	22.7
	Overhead spray	3.72	151	583	0.638	0.821	0.315	22.9
Irrigation treatment averages								
0%		1.67d†	152	334	0.500c	—	0.328a	24.7b
33%		2.60c	87	385	0.674b	0.800a	0.334a	26.0at
67%		3.63b	100	516	0.703ab	0.836a	0.339a	26.8a
100%		4.50a	64	596	0.756a	0.809a	0.360a	26.6a
100% delayed		3.11	85	517	0.601	0.575	0.355	22.7
100% early termination		3.88	125	557	0.698	0.883	0.319	23.0
Irrigation method averages								
	LEPA sock	3.19a	108	465	0.670a	0.918a	0.327a	24.9a
	LEPA bubble	3.07a	92	459	0.668a	0.752a	0.354a	25.0a
	Overhead spray	3.03a	102	459	0.638a	0.774a	0.341a	25.0a

* Includes 182 mm growing season precipitation from planting to 15 June.

† Averages followed by the same letter are not significantly different ($p \leq 0.05$). Sprinkle methods averaged across irrigation amount treatments only.

Table 5. Grain yields, soil water depletion, ET, water use efficiency, harvest index and seed weight for the 1995 wheat crop

Irrigation Treatment	Sprinkler Method	Soil Water		ET* (mm)	WUE (kg/m ³)	IWUE (kg/m ³)	Harvest Index	Seed Weight (mg)
		Yield (Mg/ha)	Depl. (mm)					
0%	Average	2.19	76	358	0.614	—	0.412	21.0
33%	LEPA sock	4.05	110	517	0.783	0.959	0.385	21.8
	LEPA bubble	3.62	89	496	0.730	0.739	0.424	21.6
	Overhead spray	3.98	41	448	0.888	0.924	0.399	21.5
67%	LEPA sock	4.58	103	635	0.721	0.749	0.356	20.5
	LEPA bubble	4.64	116	648	0.715	0.766	0.368	20.5
	Overhead spray	5.00	66	598	0.836	0.879	0.399	21.1
100%	LEPA sock	4.48	76	732	0.612	0.516	0.311	19.3
	LEPA bubble	4.51	79	736	0.613	0.524	0.355	19.9
	Overhead spray	5.28	93	750	0.703	0.695	0.362	20.2
100% Delayed	LEPA sock	4.38	114	671	0.653	0.638	0.346	19.8
	LEPA bubble	4.52	99	656	0.689	0.677	0.365	20.1
	Overhead spray	4.36	78	635	0.687	0.632	0.351	19.8
100% Early termination	LEPA sock	4.33	119	751	0.577	0.511	0.294	19.3
	LEPA bubble	4.38	80	712	0.616	0.524	0.320	19.0
	Overhead spray	4.43	57	688	0.644	0.536	0.327	19.3
Irrigation treatment averages								
0%		2.19c†	76	358	0.614b	—	0.412a	21.0a
33%		3.88b	80	487	0.797a	0.874a	0.403ab	21.6a
67%		4.74a	95	627	0.756a	0.798a	0.375bc	20.7a
100%		4.76a	83	739	0.643b	0.578b	0.342c	19.8b
100% delayed		4.42	97	654	0.676	0.649	0.354	19.9
100% early termination		4.38	85	717	0.611	0.524	0.314	19.2
Irrigation Method Averages								
	LEPA sock	3.85a	87	556	0.698ab	0.741a	0.368a	20.7a
	LEPA bubble	3.76a	93	562	0.669b	0.676a	0.387a	20.7a
	Overhead spray	4.07a	71	540	0.745a	0.832a	0.394a	20.9a

* Includes 213 mm growing season precipitation from planting to 15 June.

† Averages followed by the same letter are not significantly different ($p \leq 0.05$). Sprinkler methods averaged across irrigation amount treatments only.

early termination treatment (I_E) permitted 69 mm greater depletion than I_{100} which partially offset the 100 mm greater irrigation. However, the delayed irrigation treatment (I_D) only increased depletion 28 mm over I_{100} . Deficit irrigation levels, particularly with moderate deficits, and early seasonal irrigation cutoff permitted greater depletion of stored soil water, a management strategy that can reduce seasonal irrigation requirements. For 1995, mean soil water depletion varied in the narrow range of 76 to 97 mm because 162 mm of rainfall during May and early June replenished the soil profile for all irrigation treatments.

GRAIN YIELDS

Grain yields for each of the sixteen sprinkler method-irrigation amount combinations are listed in tables 4 and 5 for the two respective years. Grain yields did not vary significantly among the spray and LEPA sprinkler methods ($p \leq 0.05$) although in 1995 yields with the spray method were generally larger. In 1994, grain yields increased about 1 Mg/ha for each irrigation amount increment, and all irrigation-amount treatments were significantly different ($p \leq 0.05$). In 1995, the I_0 to I_{33} and I_{33} to I_{67} irrigation increments increased grain yields by 1.68 and 0.86 Mg/ha, respectively, but the I_{67} to I_{100} increment had no effect. A two-way analysis of variance with randomized blocks was used for the irrigation amount treatments defined by equally sized increments of irrigation water.

Grain yields for the two irrigation timing treatments are also listed in tables 4 and 5. In 1994, the 100% early termination irrigation treatment yielded 0.25 Mg/ha more than the comparable I_{67} treatment while the 100% delayed irrigation treatment yielded 0.52 Mg/ha less. In 1995, both the 100% delayed and 100% early termination irrigation treatments yielded about 0.35 Mg/ha less than the comparable I_{67} treatment.

Seed weight and harvest index defined as grain weight divided by total aboveground dry matter are listed in tables 4 and 5. Harvest index increased with each increase in irrigation amount in 1994, but the increases were not significant ($p \leq 0.05$). In 1995, the trend reversed with the non-irrigated harvest index being significantly larger than the irrigated harvest indices, and the harvest index for 100% irrigation being significantly less than those for the deficit-irrigated treatments ($p \leq 0.05$). In 1994, seed weight increased significantly with irrigation amount, but in 1995, seed weight was significantly smaller with 100% irrigation than for the other irrigation amounts ($p \leq 0.05$). Neither harvest indices nor seed weights were significantly different among the sprinkler methods ($p \leq 0.05$).

WATER USE EFFICIENCY AND EVAPOTRANSPIRATION

Water use efficiency calculated as grain yield divided by ET is listed in tables 4 and 5 for the sprinkler method-irrigation amount combinations. The ET value is the sum of irrigation, precipitation and soil water depletion to the 1.8 m depth. For both years, WUE for the non-irrigated treatment was significantly less ($p \leq 0.05$) than for the three irrigation amount treatments. In 1994, WUE increased with each increase in irrigation amount, and WUE for I_{100} and I_{67} was significantly larger than for I_{33} . In 1995, WUE for the two deficit irrigation amounts was significantly larger than for I_{100} ($p \leq 0.05$). Water use efficiency was not significantly different among the sprinkler methods in 1994, but overhead spray was significantly more efficient than LEPA bubble in 1995 ($p \leq 0.05$).

Irrigation water use efficiencies (IWUE) calculated as the irrigated yield minus the non-irrigated yield divided by the irrigation amount are also listed in tables 4 and 5. Irrigation water use efficiencies were not significantly different for the sprinkler methods or the irrigation amounts in 1994 ($p \leq 0.05$). In 1995, IWUE was significantly larger for deficit irrigation than for 100% irrigation.

Seasonal ET for non-irrigated to 100% irrigation ranged from 334 to 596 mm in 1994 and 358 to 739 mm in 1995, tables 4 and 5. In 1995, seasonal ET for the fully irrigated wheat was within the range of ET measured with weighing lysimeters (Howell et al., 1995), and in 1994 it was somewhat less. Grain yield as a function of ET for the

deficit-irrigated, 100%-irrigated, and irrigation timing treatments are plotted separately in figure 2. The 0.915 kg/m^3 regression coefficient for the deficit-irrigated treatments was highly significant ($p \leq 0.0001$), and the data are similar to that summarized by Musick et al. (1994) for both dryland and irrigated wheat in the Southern High Plains. For the irrigation timing treatments, the 0.550 kg/m^3 regression coefficient was also highly significant ($p \leq 0.001$), but this smaller regression coefficient illustrates the difficulty of timing irrigations in relation to rainfall and stage of plant growth. For the 100%-irrigated treatments, the 0.220 kg/m^3 regression coefficient was not significantly different from zero. These data are represented by the yield plateau curve drawn through the 4.63 Mg/ha treatment average and intersecting the deficit-irrigated curve at (608 mm, 4.63 Mg/ha).

DISCUSSION

In this study, the LEPA and overhead spray sprinkler methods were equally efficient for irrigation of winter wheat in the Southern High Plains. The equal yields with 100% irrigation are similar to those measured with corn and grain sorghum (Schneider and Howell, 1995a, 1995b). These field crops produce nearly equal yields over a range of ET values that can be as much as 10 to 15% less than full ET. As a result, any increases in irrigation efficiency due to LEPA is offset by the crop producing nearly maximum yields at less than maximum ET. The equal yields with deficit irrigation were not expected; however, and we do not have data to explain why. Not meeting the criterion of having all plants equally spaced from a LEPA applicator may partially explain the lack of response to deficit irrigation with the LEPA system. On the deficit-irrigated plots, the wheat plants under the applicators were generally taller than those between the applicators.

In 1994, grain yields increased equally for the three irrigation amount increments, but in 1995 the main yield increases resulted from the first two irrigation increments with little increase from 67% to 100% irrigation. Since the main advantages to using the LEPA method have occurred with deficit irrigation, the lack of response to 100% irrigation in 1995 would not be expected to change the conclusions from the study.

For LEPA irrigation of wheat, there has been some concern about runoff from flat-planted fields and damage from dragging socks through the crop. With our irrigation termination dates of 9 June and 23 May the wheat plants were still green enough to recover from the LEPA socks being dragged through the field. We did observe some runoff from the fully irrigated LEPA plots, but the dense wheat foliage minimized runoff, and we would not consider it a problem on commercial wheat fields. From a practical viewpoint, there was no problem using the LEPA method to irrigate winter wheat, but there was no advantage to using the more expensive application device.

CONCLUSIONS

In this comparison of LEPA and spray irrigation of winter wheat in the Southern High Plains, grain yields did not vary significantly among the LEPA and overhead spray sprinkler methods.

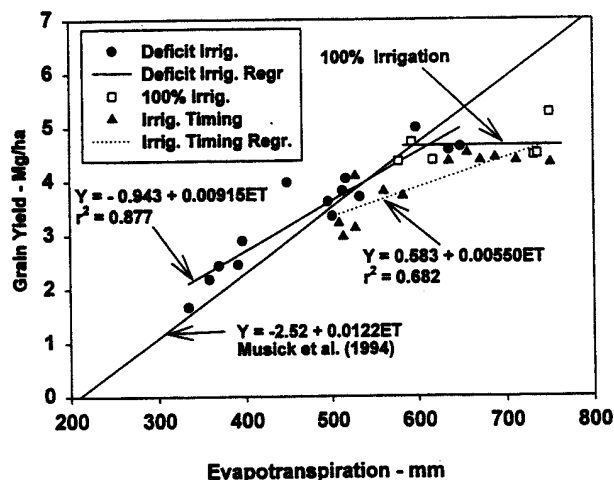


Figure 2—Grain yield as a function of ET for the two cropping years.

Grain yields were significantly increased by irrigation amount with a 1 Mg/ha yield increase for each 33% increase in irrigation in 1994 and a similar increase for the deficit irrigated wheat in 1995.

WUE, an index of efficient use of ET, generally increased with irrigation amount; whereas, IWUE, an index of efficient use of irrigation water, was largest with deficit irrigation.

REFERENCES

- Dusek, D. A. and J. T. Musick. 1992. Deficit irrigation of winter wheat: Southern Plains. ASAE Paper No. 92-2608. St. Joseph, Mich.: ASAE.
- English, M. and B. Nakamura. 1989. Effect of deficit irrigation and irrigation frequency on wheat yields. ASCE, *J. of Irrig. and Drain. Eng.* 115(2):172-184.
- Fangmeier, D. D., W. F. Voltman and S. Eftekharzadeh. 1990. Uniformity of LEPA irrigation systems with furrow drops. *Transactions of the ASAE* 33(6):1907-1912.
- Fipps, G. and L. L. New. 1990. Six years of LEPA in Texas — Less water, higher yields. In *Proc. of the Third Nat. Irrig. Symp.*, 115-120. St. Joseph, Mich.: ASAE.
- Howell, T. A., J. L. Steiner, A. D. Schneider and S. R. Evett. 1995. Evapotranspiration of winter wheat — Southern High Plains. *Transactions of the ASAE* 38(3):745-759.
- Jensen, M. E. and W. H. Sletten. 1965. Evapotranspiration and soil moisture-fertilizer interrelations with irrigated winter wheat in the Southern High Plains. USDA-ARS Cons. Res. Rpt. No. 4. Washington, D.C.: USDA.
- Lyle, W. M. and J. P. Bordovsky. 1981. Low energy precision application (LEPA) irrigation system. *Transactions of the ASAE* 24(5):1241-1245.
- . 1983. LEPA irrigation system evaluation. *Transactions of the ASAE* 26(3):776-781.
- Musick, J. T., O. R. Jones, B. A. Stewart and D. A. Dusek. 1994. Water-yield relationships for irrigated and dryland wheat in the U.S. Southern Plains. *Agron. J.* 86(6):980-986.
- Musick, J. T. and K. B. Porter. 1990. Wheat. In *Irrigation of Agricultural Crops*, 597-638, eds. B. A. Stewart and D. R. Nielsen. Madison, Wis.: Am. Soc. Agron.
- Musick, J. T., F. B. Pringle and J. D. Walker. 1988. Sprinkler and furrow irrigation trends — Texas High Plains. *Applied Engineering in Agriculture* 4(1):46-52.
- Musick, J. T. and J. D. Walker. 1987. Irrigation practices for reduced water application — Texas High Plains. *Applied Engineering in Agriculture* 3(2):190-195.
- Schneider, A. D., J. T. Musick and D. A. Dusek. 1989. Efficient wheat irrigation with limited water. *Transactions of the ASAE* 12(1):23-26.
- Schneider, A. D. and T. A. Howell. 1990. Sprinkler efficiency measurements with large weighing lysimeters. In *Proc. of the Third Nat. Irrig. Symp.*, 69-76. St. Joseph, Mich.: ASAE.
- Schneider, A. D. and T. A. Howell. 1993. Reducing sprinkler evaporation losses. In *Proc. of the Central Great Plains Irrigation Short Course*, 43-46. Manhattan, Kans.: Kansas State University.
- . 1995a. Grain sorghum response to sprinkler application methods and system capacity. *Transactions of the ASAE* 38(6):1693-1697.
- . 1995b. LEPA and spray irrigation in the Southern High Plains. In *Proc. of the First International Conference*, Vol. 2, 1718-1722. Am. Soc. of Civil Eng.
- Unger, P. W. and F. B. Pringle. 1981. Pullman soils: Distribution, importance, variability & management. Texas Agric. Expt. Sta. Bull B-1372. College Station, Tex.: Texas A&M University.